Monitoring vibrations and microdisplacement for "pin on disc" tribology studies

A E Tyurin[1], G M Ismailov[2], E V Beloenko[3], A V Baranov[3]

[1] ITMO University, St. Petersburg, Russia
[2] Tomsk State Pedagogical University, Tomsk, Russia
[3] Tomsk Polytechnic University, Tomsk, Russia

E-mail: bew@tpu.ru

Abstract. The paper studies the example of applying accelerometers to evaluate tribocoupling vibration characteristics and verification methods in the testing system "pin on disc". Microelectromechanical systems (MEMS) intended for operation over a wide static and spectral ranges were applied. Accelerator spatial track recovery was implemented through the double integration algorithm. In the course of the work, the vibrations occurring through the friction between fluorocarbon and brass alloy LS59-1 under the conditions of dry friction were studied.

1. Introduction

One of the most relevant problems of the modern science is studying friction and wear [1]. A lot of Russian research and educational institutions research the topic mentioned. Studying the basis of tribology leads to the following application results: machinery lifetime extension, increase of vehicles and machinery efficiency, reduction of dangerous release amount. Friction studying clashes with various problems, such as excitation force influencing friction joints, which have periodic intermittence and diverse frequency content, vibrations, surface microrelief. Friction generates various types of vibration accompanied by different magnitudes of velocity and acceleration.

Taking into consideration the above-mentioned, it is necessary to record vibration accelerations from external sources and surface defects. The experiment on monitoring vibrations and vibration accelerations with the use of microelectromechanical acceleration sensors was developed to solve such problems.

2. Measuring pin vibration accelerations in tribo-contact.

Accelerometers of various types are used for finding, detecting and controlling vibrations in mechanisms and measuring the vector of vibration acceleration, magnitude of the acceleration and other parameters. Currently, the most popular accelerometers are those made by technology MEMS (microelectromechanical systems). The technology mentioned enables creating an accelerometer having high-performance capability combined with low power consumption, diminutiveness and low price. MEMS accelerometer represents a polysilicon plate (mechanically connected with a substrate by the force of suspension springing elements held by "anchors"), which is capable of moving towards the single degree-of-freedom under acceleration (Fig.1). Movement of the flexible plate in relation to these fixed beams enables monitoring the acceleration.

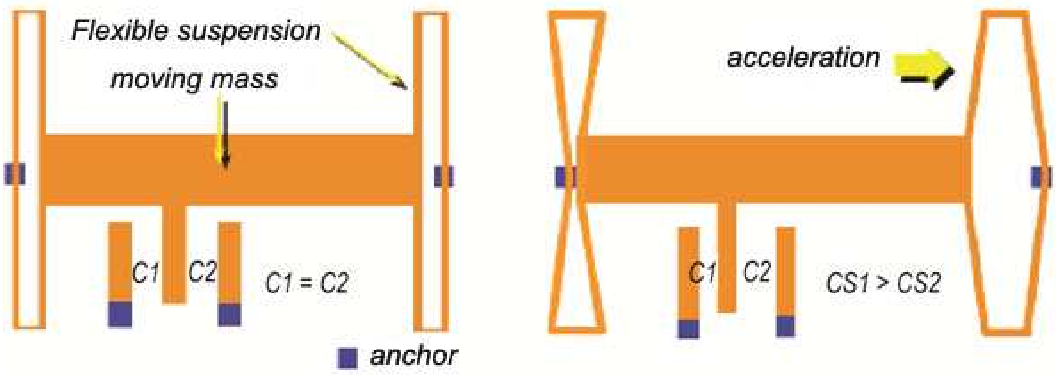


Figure 1. A differential measurement system based on paired containers

The range of accelerometers application is defined by their main parameters and their correlation. The most significant parameters are the range of the accelerations measured, sensitivity, nonlinearity, null temperature drifts.

One of the leaders in the sphere of MEMS accelerometer production is the company "Analog Devices". Company catalogue contains accelerometers with one, two and three sensitivity axes intended for the maximum acceleration equal to 1.5-250 g. An ADXL family is a set of basic devices in which a sensor and electronics are implemented on a single chip.

When choosing accelerometers for monitoring pin vibrations, the following factors were taken into account:

1) analog output, low output impedance;
2) low noise level and high output signal;
3) acceptable dynamic range and bandwidth resolution;
4) lack of necessity to the output signal amplification;
5) small size and measuring along three orthogonal axes.

MEMS accelerometers with different output signal levels (420mV/g and 57mV/g) were used as acceleration sensors. Two accelerometers were used in consequence of the ambiguity of vibration acceleration values in the course of different materials testing.

Accelerometers connection diagram is given in figure 2.

Table 1. Accelerometers applied, main specifications

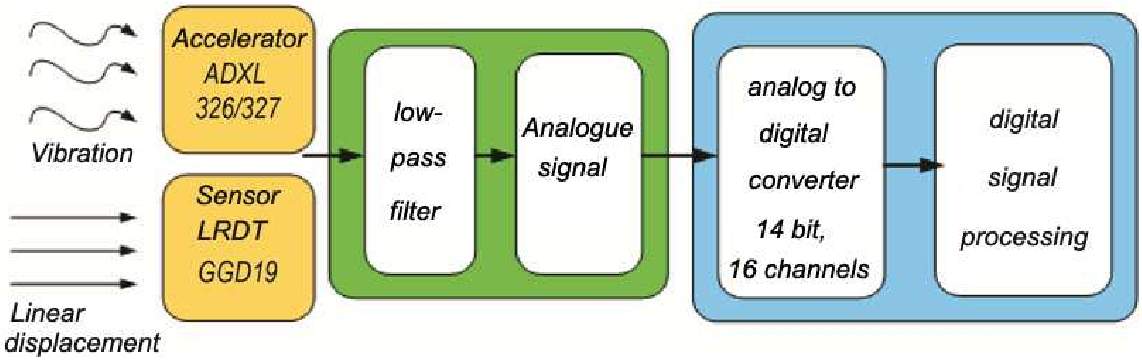
Main specifications	ADXL 326	ADXL 327
Acceleration (max.), ±g	16	2
Axes	XYZ	XYZ
Nonlinearity, %	0.3	0.3
Sensitivity, mV/g	57	420
Cut-off frequency, hz	X, Y – 1 600, Z – 500	X, Y – 1 600, Z – 500
Voff 0g, V	1.5	1.5
Source voltage, V	from 1.8 to 3.6	from 1.8 to 3.6
Absorbed current, μA	350	350
Temperature, C	from –40 to 85	from –40 to 85
Package information	LFCSP-16	LFCSP-16

An indispensable element of the measurement system is an analogue circuit of the source voltage stabilization, pickup cancellation. The circuit was based on the precise repeaters for matching the input impedance at the input of an analog-to-digital converter. Signal from the sensor passed only through the repeater and was subjected to digitization straightway and only after this the digital signal was processed. Filters were used for rejecting the high-frequency component of the signal.

3. Experiment unit

The instrument (figure 2,a) tested at the schematic circuit was created for carrying out the experimental research. The scheme of pin 2 on disc *1* contact was implemented mechanically (figure 2,b). The drive unit consists of induction motor 3, which drives the disc through sequential belt transmission *4*. Accelerometer ADXL 327 *5* measures vibration accelerations within the range of 0 to 19 m/s^2, accelerometer ADXL 326 *6* measures vibration accelerations within the range of 0 to 150 m/s^2. *5*, *6* are oriented relative to the coordinate system and are set directly on the pin. Position *7* is the linear displacement sensor. The speed was regulated discretely with the use of rollers of various diameters and with speeds from 250 to 2000 r/min. Friction counterpressure (the pin fixed on a special holder) can move along two coordinate axes. Contraction is provided by spring adjusting screws in x-direction by the spring with the force equal to k_1, in z-direction by the spring with the force equal to k_2.

a



b

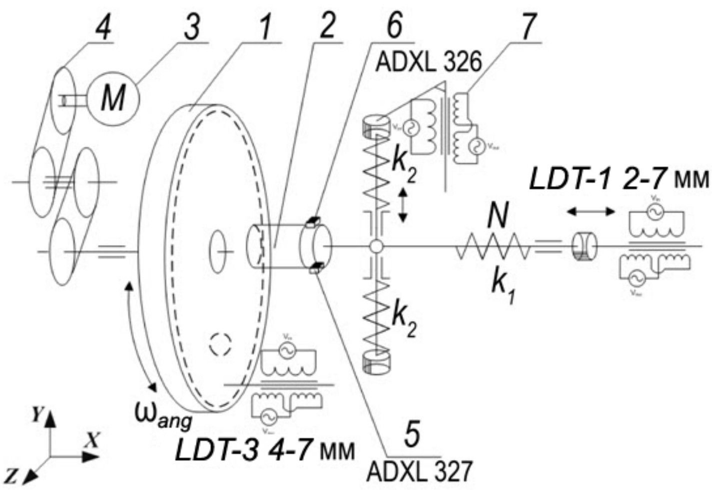


Figure 2. An experimental unit for studying tribocoupling by the studies «pin on disc»: *a*) a measurement system structure; b) an electromechanical part.

The platform with acceleration sensors *5*, *6*, enabling to get information on vibration on the sample under research is tightly fixed on the sample. Vibration occurs in case of contacting with the friction surface; data must be registered along each of the axes 0 to 19 m/s^2 and 0 to 150 m/s^2.

4. Experimentation

Research was conducted for three alloy samples: LS59-1, St30HGS, AT3 and a disc made of fluorocarbon, at different friction modes. The following values were measured: vibration, interface pressure, speed, temperature of the fixed pin sample and external temperature [1, 2, 3].

Vibration amplitude versus time is presented in figure 3. Sampling frequency is equal to 2 khz and enables monitoring signals from acceleration sensors to the cut-off frequency equal to 1 khz, if there is capacitor C1 at the signal output of 50 nanofarad (figure 4) with ADXL326/327 along two axes *X*, *Y*.

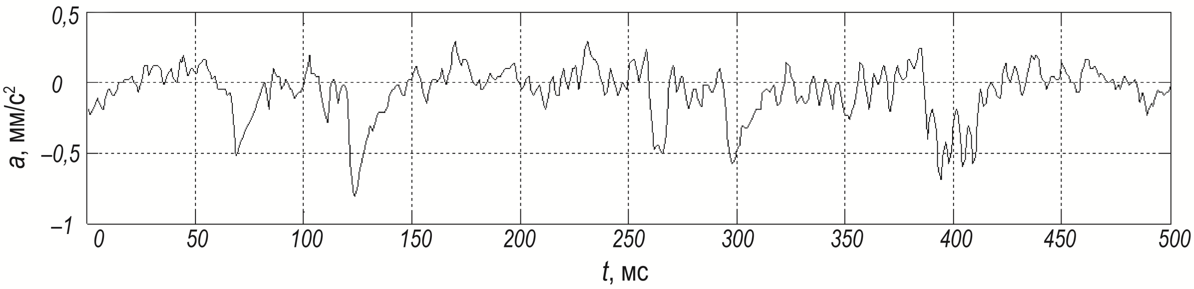


Figure 3. The signal from the vibration sensor along axis X after filtration, on the frequency band from 15 to 1000 hz and deleting elementary units multiple of 50 hz.

It is rather complicated to spot the peculiarities of a signal taking into account its form; let us use signal spectral representation for aliases evaluation. To obtain the spectral distribution, discrete Short Time Fourier Transform with the window width equal to 4 096 was applied.

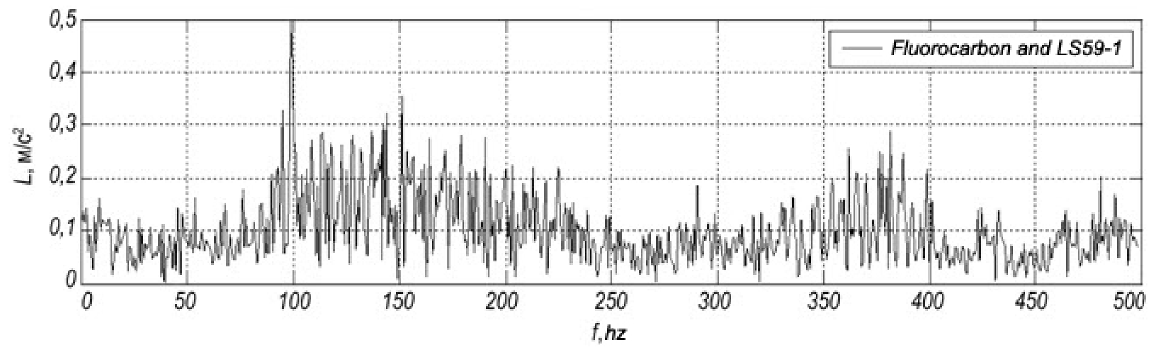


Figure 4. Vibration acceleration spectrum after filtration and front-end processing, gained while researching the wear during 30 minutes of the experiment, friction couple fluorocarbon and LS59-1.

Increased wear of the couple fluorocarbon and bronze in comparison to the wear of the couple fluorocarbon and steel is proved by experiment. Vibration acceleration spectrum of the friction couple fluorocarbon-4 and LS59-1 shown in figure 4 is shifted to the low-frequency region, which occurs due to the friction surface roughness and bronze characteristics.

5. Recovery of pin's microdisplacemens trajectory

Trajectory recovery is possible by data from accelerometer; speed is restored with the help of integration, vibration displacement is obtained by repeated integration of acceleration. Phase trajectory is fixed by one certain period; consequently, fixation during another time interval allows singling out the processes of hardiness in the system (figure 5).

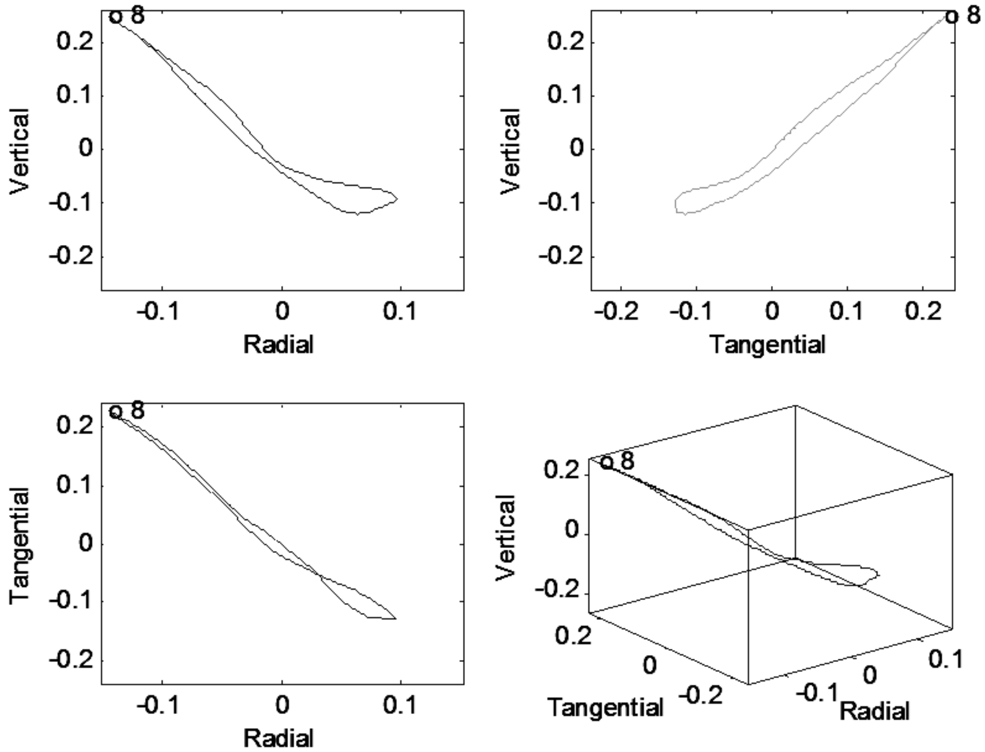


Figure 5. Trajectory recovery by the data on vibration displacement in different coordinates' combinations.

6. Main findings and conclusion

Using AD accelerometers allowed measuring vibration accelerations along three axes in different frequency bands; circuit designed on their basis enabled to modernize the experiment unit, implement the measuring task with the help of a simple and functional circuit [4,5]. In consequence of the above mentioned, the capabilities of the measuring tribotechnical system "pin on disc" were advanced, three measuring channels of vibration acceleration were added. Fluorocarbon and brass were studied on the sophisticated measuring system. Applying accelerometers enabled to complement the information on the processes occurring in tribo-contact and single out new regularities.

References

[1] Musalimov W, Musalimova L, Dudyeva E 2011 Shears of helical reinforcement in the deformed composite Original Research Article *Procedia Engineering* **10** 1426-1432

[2] Kopytenko Y A, Sergushin P A, Petrishchev M S, Levanenko V A, Perechesova A D 2010 Device for manufacturing torsion bars with helical anisotropy UISAT-1 *Key Engineering Materials* **437** 625-628

[3] Hlebová S, Ambriško L, Pešek L 2014 Strain measurement in local volume by non-contact videoextensometric technique on ultra high strength steels *Key Engineering Materials* **586** 129-132

[4] Sun W, He X-Y, Huang Y-P, Xu Z-B, Liu W-W 2008 Experimental study on identification of modal parameters of cable *Engineering Mechanics* **25(6)** 88-93

[5] Martín S C, Betsch P, Orden J C G March 2016 A temperature-based thermodynamically consistent integration scheme for discrete thermo-elastodynamics Original Research Article *Communications in Nonlinear Science and Numerical Simulation* **32** 63-93